Preliminary Investigations on the Fate of Terrestrial Sediments in the Coastal Ocean Discharged From Taiwanese Small Mountainous Rivers

Kon-Kee Liu
Institute of Hydrological & Oceanic Sciences, National Central University
300 Jung-da Rd., Jhongli, Taiwan 32001
phone: +886-3-422-3354, fax: +886-3-422-2894, email: kkliu@ncu.edu.tw

Wen-Son Chiang
Tainan Hydraulics Laboratory, National Cheng-Kung University
500 An-Ming Road Sec. 3, Tainan, Taiwan 701
phone: +886-6-237-1938 ext 232, fax: +886-6-3840206, email: chws@mail.ncku.edu.tw

Hwa Chien
Institute of Hydrological & Oceanic Sciences, National Central University
300 Jung-da Rd., Jhongli, Taoyuan, Taiwan 32001
phone: +886-3-422-7151 ext 65690, fax: +886-3-422-2894, email: hchien@ncu.edu.tw

Shu-Kun Hsu
Department of Earth Science & Institute of Geophysics, National Central University
300 Jung-da Rd., Jhongli, Taoyuan, Taiwan 32001
phone: +886-3-422-7151 ext 65620, fax: +886-3-422-2044, email: hsu@ncu.edu.tw

Shuh-Ji Kao
RCEC Academia Sinica, 128 Academia Rd. Sec.2, Nankang, Taipei, Taiwan 115
phone: +886-2-2693-5885 ext 252, fax: +886-2-2783-3584, email:
sjkao@gate.sinica.edu.tw

James T. Liu
Institute of Marine Geology and Chemistry, National Sun Yat-sen University
70 Lienhai Rd., Kaohsiung, Taiwan 80424
phone: +886-7-525-5144, fax: +886-7-525-5130, email: james@mail.nsysu.edu.tw

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LONG-TERM GOALS

The long-term goal is to better understand sediment transport processes that are critical to our overall understanding on the fate of terrestrial sediment in the coastal ocean. This project makes the best use of the very high production rate of sediments on Taiwan. The sediment laden rivers of Taiwan may provide opportunities for direct observations of the fluid-sediment processes occurring during hyperpycnal plume events and other highly dynamic sediment transport processes.

OBJECTIVES

The objective of this project is to carry out preliminary studies on sediment discharge in Taiwanese rivers and their deposition in the coastal environments. The final report of this 3-year project will be used to create a comprehensive white paper for ONR Coastal Geosciences Program in order to propose an international collaborative, large-scale process-based field experimental initiative on FY11 that is relevant to Naval applications and interests.

APPROACH

At the selected rivers and their neighboring shelves, small pilot experiments were executed during pre-, during (if feasible) and post-flood periods. These experiments were collectively conducted by researchers and scientists from NCU, Academia Sinica (AC), National Sun-Yet San University (NSYSU) and Tainan Hydraulic Laboratory (THL). The purpose is to test several field observational approaches, which may be applicable during extreme weather events, such as floods or storm surges during typhoons. Small scale and less expensive equipments were deployed to check their endurances under severe conditions.

WORK COMPLETED

In 2008, extremely heavy rainfalls occurred in the Jhoushuei watershed during the landfall of typhoon Kalmaegi and Jangmi incurred hazardous inundation in the southwestern coast of Taiwan. During the passage of these typhoons, field surveys of fluvial discharge and suspended sediment concentration on the bridges were carried out and demonstrated the onset of high density riverine flow (>200 g/l). The sediment yield exceeded 36 Mton within 48 hours during typhoon Kalmaegi. Field observations in the estuary were implemented immediately right after the passage of typhoons (40 hrs after the peak fluvial discharge). A bottom-mount station, equipped with optical backscatter sensors array and ADCP was setup to measure the suspended sediment concentration profiles, waves and tidal currents. Concurrent measurements by towed ADCP, water sampling at various depths, OBS and CTD probing were preformed on vessels along the 13 km transaction track from the river mouth. The shipboard surveys were implemented more than 9 hours to obtain data coverage over the ebb and flood of a tidal cycle. Satellite water color images from Formosa II were also retrieved for analysis.

A bottom-mount instrumented station was deployed directly offshore of the Jhoushuei River mouth and shipboard survey transaction was designed with the primary objective of characterizing sediment transport along the seabed offshore of the river. The station and shipboard surveys were implemented on July 19~20 and Oct. 20, 2008 to observe the aftermath of Kalmaegi typhoon and Jangmi typhoon, respectively. The station was placed about 1.5 km offshore of the river mouth with the water depth ranging from 8 ~ 11 m .

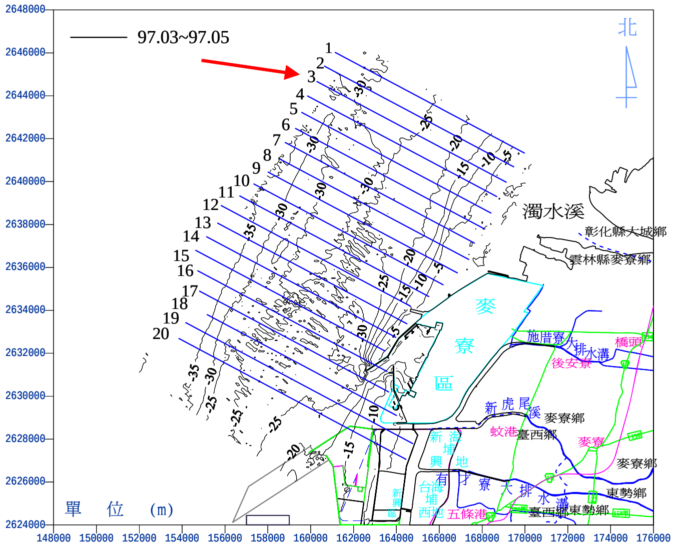

Fig 1 Bathymetric map at the Jhoushui River month.

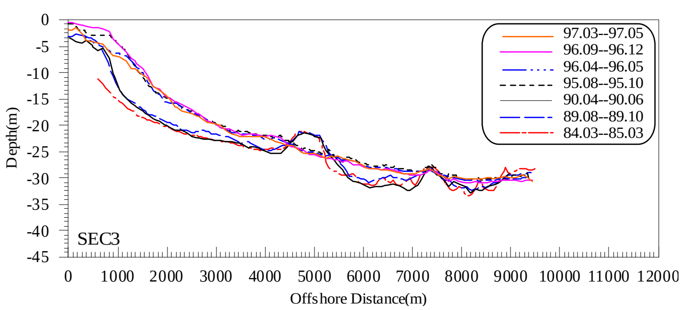

Fig 2 Variations of bottom slope of transaction 3 as indicated in Figure 1. (Year in Republic year: 84.03 = Mar 1995; 89.08 = Aug 2000; …; 96.09 = Sep 2007; 97.03 = March 2008)

The tidal difference at the Jhoushue estuary is about 3 m on average. The bottom-mount station was equipped with optical and acoustic sensors, including a 600 kHz RDI acoustic Doppler current profiler (ADCP) at 0.5 m above the seabed, and an optical suspended sediment concentration profiler (SSCP). The 600 kHz ADCP back scatter was used to measure the water elevation, current velocity profile. Moreover, its echo intensity was used to estimate the suspended sediment concentration profile. The vertical resolution was set to 0.5 m.

The 2 m high SSCP was set up to observe the suspended sediment concentration of the lutocline in the bottom boundary layer. The intense LED array on the SSCP made it capable of resolving centimeter scale variations. Unfortunately, this SSCP malfunctioned 6 hours after deployment due to damages inflicted by trawl-fishing meshes.

A cross-shelf survey transect with 7 stations was designed. The locations of the 7 stations are illustrated in Fig. 3. The total distance between Station A near the river mouth to the offshore Station F is 13 km, about 1.5 hour of cruise time. The vessel traveled along the transect back and forth for 6 times acquiring data from ebb to flood over the tidal cycle. The vessel was a small plastic fishing raft which enabled us to reach the river mouth Station A, where the water depth was very shallow. The survey was conducted with a RDI 600kHz towed ADCP with bottom tracking function. The raft was equipped with a stainless frame, on which a HydroLab probe with salinity, water temperature, pressure and optical turbidity sensors was mounted, whilst an underwater pump was mounted 50 cm above the cage bottom. The pump drew water at different depths for sediment gain size and concentration analysis. Grab samples of seabed sediments were obtained on the cruise tracks. The median grain size d_{50} was determined by sieving.

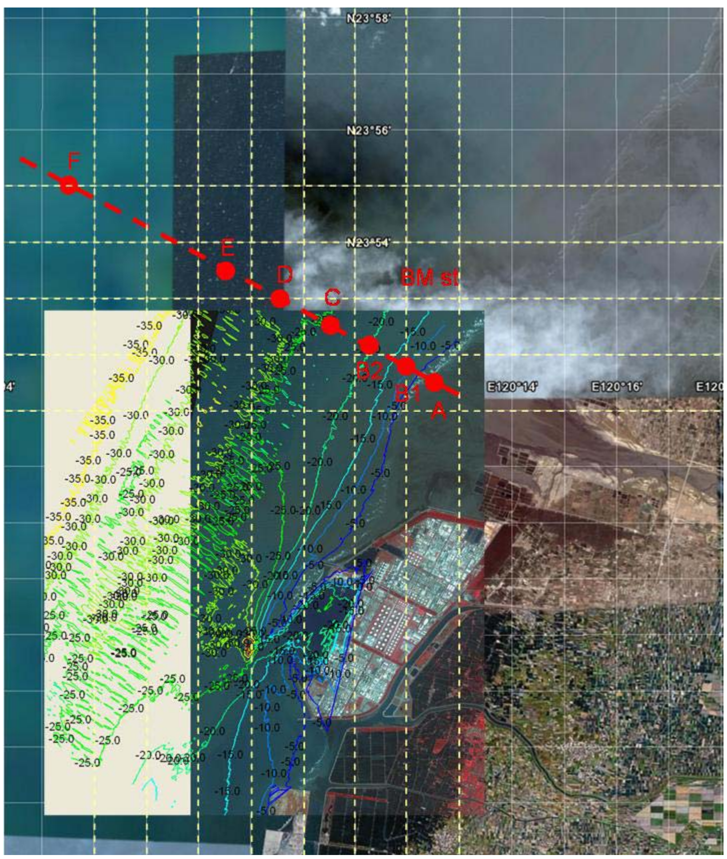

Figure 3 the locations of stations along the transect.

RESULTS

Hydrologic and meteorological data were obtained from the Water Resources Agency stations located within the Jhoushuei watershed. Comparisons with historic records reveal that the Kalmaegi discharge ranked #8 among all discharge records. Precipitation data were obtained from the Central Weather Bureau, which provided hourly rain gauge data. Sediment discharge from the Jhoushuei River was estimated using the discharge data and the suspended-sediment rating curve for the Tze-Chiang gauge complied by Hsieh.

(2000). For estimates of discharge every 3 hours, sediment discharges (Figure 4) were calculated by the product of river discharge and a discharge-dependent suspended sediment concentration rating curve. From the figure, it is implied that the fluvial discharge might have sustained hyperpycnal flow for at least 30 hours.

Coastal meteorological (wind speed and direction, atmospheric pressure) and oceanographic data (wave height, period, and direction) were acquired with the Tainan Hydraulic Lab pile station. Lastly, two satellite images of the river mouth were obtained from the NASA moderate resolution imaging spectroradiometers (MODIS) on the Aqua and Terra satellites.

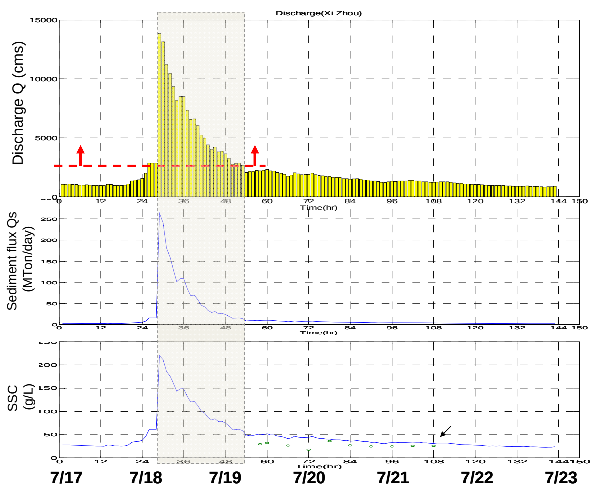

Figure 4 The time series of the river fluvial discharge, sediment discharge and the SSC variation

By the time the vessels were sent out for estuary field survey, it was about 40 hours after the fluvial peak discharge. The SSC measured from the bridge station was reduced to 26 g/l. River plume with a sharp front between turbid and clear water was observed as shown in Figure 5. The sea surface roughness exhibited visually significant differences across the frontal zone. Due to the ebb-flood oscillation of strong alongshore tidal current (up to 1.5 m/s measured by bottom-mount ADCP), the plumes were dispersed and diluted to form secondary and the tertiary frontlines, which could be identified from the satellite images. Across the frontlines, 72 samples of sea water were collected at various water depths at the stations along the transect (Fig. 3). The suspended sediment concentrations of these sampled water were used to calibrate the optical backscatter sensors and acoustic sensors for suspended sediment concentration measurement. The SSC from water samples are illustrated in Figure 6. The maximum SSC measured 50 cm above the sea bed at station A, in the vicinity (2 km) of the river mouth, was 2400 mg/l. The SSC decreased with distance from the sea bed.

It is noted that the SSC decreased from 26 g/l at the bridge station to 2400 mg/l near the bed at Station A, which was only two kilometers down stream from the bridge station. This suggests very rapid deposition of the majority of sediments, which were coarse-

grained, right at the river mouth. The median grain size (d50) was 0.3 mm. The accumulative sediment discharge of Jhoshuie River in this typhoon episode was 36 Mtons according to the sediment flux estimation. If 90% of the suspended sediment sank out of the water column, about 32.4 Mtons of sediment deposited in the estuary fan with an area of about 6.28 km^2. If this is the case, the accretion to the sea bed load may be as large as 1.9 m in thickness on average, which seems not to be the case.

Figure 5 Sharp frontline between turbid and fresh water is obvious at the boundary of river plume. The sea surface roughness varies across the frontline due to the convergence of the leading edge of the front.

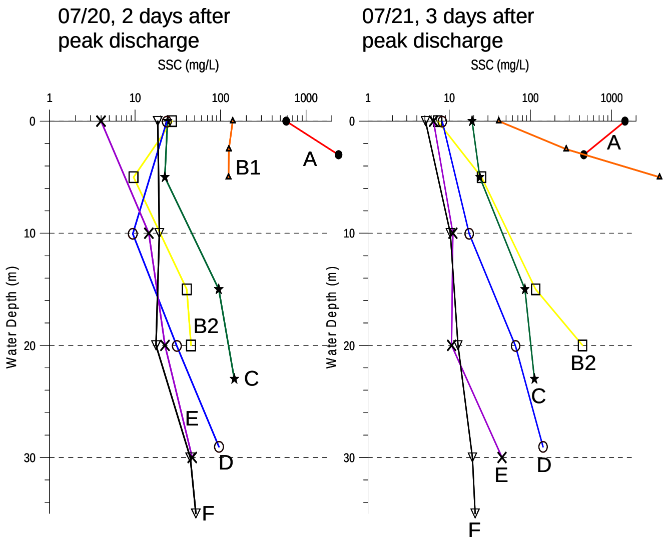

Figure 6 SSC profiles obtained from water samples in each station

Recent studies have highlighted the significance of sediment gravity flow to the transportation of sediment across continental shelves (Traykovski et al 2002, 2003, Ma et al 2008). In the Jhoushuei Estuary, the gravity-induced motion of the turbidity plume entertained the strong tidal current, which helped to maintain sediment in suspension. The current-supported gravity flows might account for the transportation of sediment from Jhoushuei River mouth to the offshore region.

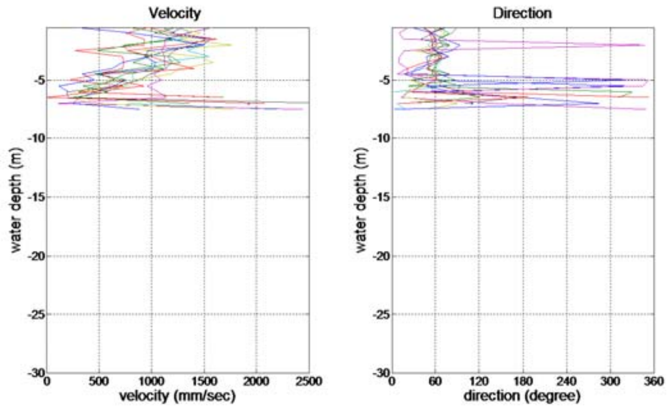

Figure 7 Features of gravity flows near the bottom off the Jhuoshui river mouth were identified. The data were scattered due to intense turbulences and high SSC.

The qualitative features of the gravity flow were investigated. Shipboard ADCP had observed the flow reaching 2m/s 50cm above the bed (one cell above the bed) along the transect from Stations B1 to B2 as demonstrated in the left panel of Figure 7. The flow velocity at the surface was about 1 m/s, nearly parallel to the coastline. This is the typical ebb-tide flow. The data were noisy due to strong turbulences and high suspended sediment concentrations. By using the momentum balance equation of the gravity flow conceptual model proposed by Wright (2001) and Traykovsky (2007), the velocity of the gravity flow could be estimated with local parameterization. For tidal current equal to 1m/s and bottom slope = 0.007, the gravity flow was estimated to be 1.88 m/s, which agreed with the observations. It is noted that the flow direction near the bottom was perpendicular to the shelf depth contour. From these data, it could be concluded that this was the gravity flow supported by the strong tidal current.

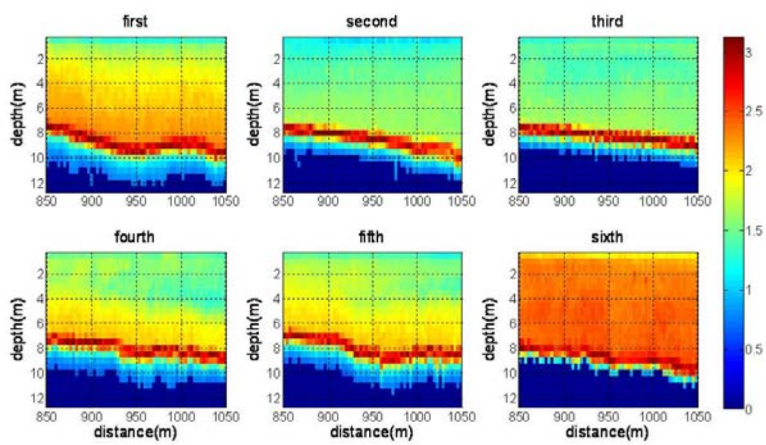

Figure 8 Sections of observed suspended sediment concentrations (g/L) on the repeated observations along the transect shown in Fig. 3.

The water samples were taken in the water column above the gravity flow. In order to estimate the density of the suspended sediments in the gravity flow from the echo intensity of ADCP, we took two approaches, i.e. the random phase acoustic backscatter model and the bottom boundary layer model-dependent inversion method. We applied these methods to the acoustic and optical backscatter data to infer the suspended sediment

concentration (SSC) profile. The results are compared with each other. We estimated the SSC of the gravity flow to be about 3 g/l.

IMPACT/APPLICATIONS

- Field observation showed evidence of the occurrence of gravity-driven flow, which might play an important role in the offshore transport of Jhoushuei River discharged sediments.
- The gravity flow sediment concentration exceeded several g/l, but not yet reached the threshold of hyperpycnal flow, which might have occurred earlier during the peak discharge.
- The mean grain size of suspended sediments in the river mouth region was about 10 times smaller than the averaged bed sediment, implying the freshly discharged sediments are not the same as the sediments remaining near the river mouth. The fate of the freshly discharged sediments is an important question for future observations.

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HONORS/AWARDS/PRIZES

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